Progress Report – FY2005

Core Name: Ecotoxicology and Aquatic Production Core

Project Title: Assessing Human Health Benefits and Risks Associated with Consumption of Farmed and Wild Seafood

Reporting Period: October 1, 2005 – September 30, 2006

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Background and Rationale:

Evaluating the benefits and risks of seafood consumption is one of the most important and timely issues directly linking the oceans and human health considerations. Seafood can be a highly nutritious component of the human diet. Although an excellent source of protein and vitamins, it is the long-chained omega-3 fatty acids found in most seafood that provide a nutritional advantage not found in other food groups. As confirmed by the National Academy of Sciences recent (October 17, 2006) report on Seafood Health Benefits and Risks, these beneficial polyunsaturated fatty acids (PUFAs) are now widely acknowledged to have positive effects on the prevention and treatment of cardiovascular diseases. Other studies suggest probable beneficial effects on neurological development and the treatment of inflammatory and autoimmune diseases. While plants can provide some 18-carbon PUFAs, it is the omega-3 PUFAs eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) which are responsible for most of the beneficial health effects. Humans can only biosynthesize small quantities of these fatty acids, and most must be obtained through diet. Fish and shellfish are especially rich in EPA and DHA and are the primary source of these fatty acids in the human diet.

On the other hand, problems with bioaccumulation of contaminants in marine organisms can pose a real threat. Problems with methylmercury in fish flesh are well documented and the bioaccumulation of organochlorine compounds and emerging contaminants in lipids is a serious issue. With an ever larger proportion of our seafood coming from aquaculture sources, there is considerable concern over possible organic contaminants in farmed fish due to the bioaccumulation of contaminants in fishmeal-based feeds. Issues related to the safety and quality of farmed shrimp have also received much attention, impacting trade between major producing and consuming countries. Although the fatty acid benefits and contaminant risks of seafood are widely recognized, much more survey work is necessary to describe the variability found in different sources. It is particularly important to establish these ranges of variability in order to design aquaculture studies to improve the quality of seafood brought to market. The OHH Seafood Benefits and Risks project focuses on marine finfish and shrimp as these are key seafood products consumed in the United States. The goal of the present research is twofold. First, the project has

surveyed the health benefits (fatty acid profiles) and risks (contaminant levels) associated with selected farmed and wild sources of fish and shrimp available on the US market. Second, controlled experimental studies are exploring the effects of diet formulation on the quality and safety of farmed seafood products.

Objectives:

- Develop a better understanding of the human health benefits and risks associated with cultured and wild seafood by assessing the variability of contaminants and beneficial fatty acids in a representative finfish and crustacean.

- Develop and transfer to users aquaculture technologies that permit economically competitive production of seafood with safe contaminant levels and enhanced beneficial fatty acid profiles.

Accomplishments:

- During FY2004 wild red drum were collected at six "clean" and six "impacted" sites in North Carolina, South Carolina, east coast Florida, west coast Florida, Louisiana, and Texas. Farmed red drum were collected from three domestic sites in Texas, Mississippi, and Florida and three imported sites in China, Taiwan, and Thailand. During FY2005 fillets were analyzed by NOAA and NIST collaborators for fatty acid profiles and contaminants: metals, pesticides, PCBs, PBDE's, PAHs, and methylmercury.

  Wild red drum have among the lowest levels of total lipids, DHA, and EPA of major commercial and recreational marine finfish. Differences in fatty acid profiles of fillets probably reflected differences in diets. Farmed fish have significantly higher total lipid, DHA, and EPA levels than wild fish, and imported farmed fish were higher for these parameters than domestically cultured fish. Farmed red drum also displayed much higher levels of linoleic acid (LA) than wild-caught fish, reflecting the large amounts of plant ingredients (e.g. soybeans, corn, etc.) in aquaculture diets. Principal component analysis of nine major PUFAs clearly separated wild-caught fish from farm-raised fish. Wild-caught fish from all locations clustered tightly. Farm-raised fish from China and Taiwan separated clearly from domestically raised fish and those from Thailand. This probably reflects the soybean-heavy commercial diets typical of the domestic and Thai farms.

  Interpretation of the large contaminants data set has not been fully completed. We have examined it carefully in consultation with Dr. John Vena, chair of the University of South Carolina's Department of Epidemiology and Biostatistics and he in turn has conferred with colleagues in his department. We agree that the data should be reported descriptively without drawing significant conclusions about any of the sources. Most of the contaminants measured in the samples were below detection limits and in almost all cases the values were well below USEPA screening levels or USFDA action levels. The most dramatic exception occurred

due to high levels of DDT-related pesticides found in some of the red drum farmed in Southeast Asia. In one case these levels exceeded the USEPA carcinogenic screening level for DDT compounds. None of the other contaminants exceeded any human health standards. No obvious site trends were observed for most classes of contaminants. Total PCBs were significantly greater in fish taken from "impacted" sites in East Florida, North Carolina, and South Carolina than from similar "clean" sites or from any Gulf coast sites. Domestic farms showed higher PCB levels than southeast Asian farms. We plan to explore these data more completely to focus on correlations among contaminants and possible ways to examine cumulative effects of multiple contaminants. Since red drum is the number one (by weight in 2004, NMFS) recreational fish caught along the Southeastern and Gulf coasts, achieving a better understanding of the variability in risks and benefits of its consumption will be significant to recreational and subsistence fishers and the agencies that regulate the harvest.

- Shrimp is the number one seafood consumed by Americans. Shrimp that are readily available to consumers in the southeastern U.S were collected from 62 sources. These included a variety of domestic and imported, wild and farmed sources collected between July and December 2005 to provide a good representation of stocks available to the consumer. Reflecting shrimp consumption by Americans, farmed and wild *L. vannamei* from domestic and foreign sources comprised the largest number of samples. Multiple samples of wild *L. setiferus*, *F. aztecus,* and *F. duorarum* from the Atlantic and Gulf regions and farmed imported *P. monodon* were also collected. Laboartory analyses for fatty acid profiles and chemical contaminants are not yet completed. Evaluation of these results should produce a significant database that will yield insights into the PUFA levels and harmful chemical content of shrimp from a wide range of sources.

- Diet studies of farmed red drum and shrimp were begun during FY2005. The goal is to reduce contaminants by eliminating fish meal and fish oil in dietary formulations while maintaining or enhancing the beneficial fatty acid levels of the final product. A 12-week study was conducted to determine whether a finishing diet enriched with DHA derived from a marine alga could alter the fatty acid composition of one year old red drum at the end of grow-out. The conventional diet on which the fish had been raised was top-coated with the algal-derived oil to raise the DHA level from 0.8% to 2.4%. Fish were fed either the conventional diet or the lipid-enhanced diet, sacrificed at 3 week intervals, and composites of fillets analyzed for fatty acids. While initial results from this study appeared positive, detailed analyses of the complete data set demonstrated an unacceptable level of variability. Some of the archived fillets were re-analyzed individually using different procedures for sample preparation. While the impact of the finishing diet remains inconclusive, this study has provided valuable guidance for improving the design of future diet studies. Some of these procedures involve identifying and monitoring changes in individual fish, analyzing individual whole,

skinned fillets rather than composites, and increasing sample sizes at the expense of more frequent sampling.

- A larger diet study with red drum was begun in July 2006 and is currently underway. The objective is to raise fish from 100g to 600g on diets with greatly reduced or no fish meal and fish oil ingredients. At the end of the grow-out period some fish will be switched to finishing diets to restore or enhance their levels of beneficial PUFAs. A commercial diet containing 30-40% fish meal/fish oil is the control diet. One test diet reduces the content to 5% fish meal, 5% fish oil. These ingredients are eliminated entirely in the other test diets. One of these lacks DHA while this fatty acid is supplied in the other diet by a DHA supplement derived from a marine alga. All of the experimental diets are constructed from pure ingredients by OHH Seafood personnel in the HML. Each of the original 456 fish, distributed among 24 1500 L tanks, was individually tagged, weighed, and measured. Growth parameters and fatty acid profiles are being used to measure the relative success of the four diets. A series of health problems has plagued the study almost from the outset. While it can be demonstrated that diet treatment has had a significant effect on the fish's ability to resist disease, an effect due to apparent differences in the recirculating filter systems is also significant. While the final outcome of this study is not yet determined, valuable lessons are being learned that will improve future studies in the HML Aquatic Production section.

- Research to design fish meal replacement strategies for shrimp mariculture studies has also been conducted during FY2005. Pond cultured shrimp produced in a study funded by the US Marine Shrimp Farming Program and Advanced Bionutrition Corp. have been analyzed for fatty acid profiles and chemical contaminants though the OHH Seafood Benefits and Risks program. The study evaluated a shrimp diet formulated with organically certified, non-genetically modified ingredients. Fish protein and lipids were replaced with plant proteins and algal-derived DHA. All shrimp growth and production parameters related to the organic diet proved fully equivalent to those for shrimp raised on the conventional fish meal based diet. Over 160 chemical contaminants were measured and none were present in significant levels in shrimp raised on either diet. The conventional diet provided significantly higher quantities of EPA and DHA than the plant-based diet and the conventional diet shrimp reflected this with higher levels of these beneficial fatty acids. However the relative ratios of EPA and DHA in the shrimp compared to ratios in the diets suggest specific requirements for amounts and ratios of these fatty acids in shrimp. Since, like humans, shrimp are considered to have limited ability to synthesize EPA and DHA from shorter fatty acids, it appears that shrimp either can selectively accumulate specific dietary fatty acids or have access to a supplemental food source in the ponds.

  The results of the analyses conducted on this study may open new avenues for designing feeds that enhance the level of beneficial fatty acids in the shrimp while

ensuring insignificantly low levels of chemical contaminants. The results of this study and the OHH analyses will be published in the December 2006 issue of *The Journal of the World Aquaculture Society*. These results also formed the foundation for a spin-off project funded by the USDA Organic Program. This work will explore the possibility of integrating specially designed diets with supplemental nutrition supplied by managing the microbial communities of shrimp culture systems in order to produce fully organic shrimp for the health-conscious consumer.

Publications/Presentations:

Leffler, J.W., C.L. Browdy, and T.I.J. Smith, 2006. Risk Assessment. NOAA Inititiative Examines Fatty Acids, Contaminants in Red Drum, Shrimp. *Global Aquaculture Alliance* 9(2):40-42.

Browdy, C.L., G. Seaborn, H. Atwood, D.A. Davis, R.A. Bullis, T.M. Samocha, E. Wirth and J.W. Leffler. 2006. Comparison of Pond Production Efficiency, Fatty Acid Profiles and Contaminants in *Litopenaeus vannamei* fed Organic Certifiable, Plant-based and Fishmeal-based Grow-out Diets. *Journal of the World Aquaculture Society*, in press.

The Wild and Farmed Seafood Enigma: Exploring Human Health Risks, Benefits and Opportunities for the Future. NOAA-OHHI National Conference. Charleston, SC. January 2006. Presented by C.L. Browdy with T.I.J. Smith, J.W. Leffler, G. Seaborn, and E. Wirth.

The Wild and Farmed Seafood Enigma: Exploring Human Health Risks, Benefits and Opportunities for the Future. Hollings Marine Laboratory Seminar. Charleston, SC. February 14, 2006. Presented by J.W. Leffler.

Fatty Acid Profiles and Contaminant Loads of Wild and Farmed Red Drum: Assessing Seafood Benefits and Risks. South Carolina Chapter of American Fisheries Society/ South Carolina Fisheries Workers Association. Charleston, SC. February 16-17, 2006. Presented by J.W. Leffler with C.L. Browdy, T.I.J. Smith, G. Seaborn, and E. Wirth.

Human Health Benefits and Risks of Farmed and Wild Seafood. Mariculture Section Retreat, Marine Resources Division, South Carolina Department of Natural Resources. Bluffton, SC. March 1, 2006. Presented by J.W. Leffler.

An Ecosystem Approach toward Developing Environmentally-Friendly, Sustainable and Economically Competitive Marine Shrimp Aquaculture. Grice Marine Laboratory Seminar. Charleston, SC. September 7, 2006. Presented by J.W. Leffler.

Application/Technology Transfer relevant to OHH Strategic Goals:

1.0 Scientific Research and Application

The OHH Seafood Risks and Benefits program directly addresses human health outcomes that might result from seafood consumption. Seafood products are widely recognized for both their health benefits as well as for their possible risks. Many agencies are struggling with how to advise consumers so that neither the risks nor the benefits are ignored. Our efforts are increasing understanding of the inherent variability of both the risks and benefits associated with seafood from

different geographic sources and from seafoods that are farm-raised or wild-caught. The aquaculture efforts in which we are engaged seek to produce farm-raised products that are both low in contaminants but which retain the high levels of beneficial, health-promoting fatty acids.

2.0 Public Information and Outreach

Several recent studies have suggested that farm-raised fish may carry higher health risks than wild caught fish due to contaminants concentrated in the fishmeal-based feeds on which they are raised. Our aquaculture studies seek to develop diets and methodologies that will permit fish and crustaceans to be raised most of their lives on no-fishmeal or low-fishmeal feeds. In order to ensure sufficient concentrations of beneficial fatty acids we hope to use short-term finishing diets of various types to boost EPA and DHA fatty acids to levels beneficial to human health. These methodologies will be most useful when delivered to aquaculturists who will be able to produce more healthful products.

3.0 Capacity Building

During the second year of the OHH Seafood Risks and Benefits program we have continued to strengthen coordination and collaboration with CCEHBR's (Gloria Seaborn) Marine Lipids Forensic Laboratory, CCEHBR/HML's Environmental Chemistry Core (Ed Wirth), NIST's (Steve Christopher) Analytical Chemistry laboratory, HML's Aquatic Production facility (Colden Battey), and the SCDNR Mariculture Section. Gloria Seaborn in particular has been very helpful in assisting with experimental designs, data analysis, and in reducing the turn-around time for fatty acid analyses. A strong consultative relationship with John Vena of USC's School of Public Health has been developed. Equipment has been purchased and, through collaboration with Allen Davis of Auburn University, we are now established to formulate and produce experimental diets for shrimp and finfish. As a result of the red drum finishing diet study this year, we have learned much about optimizing experimental designs for diet studies. The current red drum diet study is the first experiment to use all 24 1500 L tanks in the HML Aquatic Production facility simultaneously. We have gained valuable insights into the operation of this system and are developing protocols for its optimal use as well as management techniques for reducing parasite infestations and improving disease control. Through pilot studies with the Kelwall algal culture system in HML's Aquatic Production facility we have begun to gain an understanding of how brackish water microbial communities respond to chemical and physical manipulations. This supports work to incorporate microbial biofloc as supplemental nutrition in diets for cultivated seafood. We continue to monitor recent developments in human health research regarding contaminant risk assessment procedures as well as the cohort epidemiology and randomized trial studies that form the basis of the seafood benefits literature. These ongoing efforts toward developing capacity will increase the ability of the OHH initiative

in general and the Seafood program in particular to increase the relevance of their efforts to directly enhance human health.

Project abstract:

During FY2005, we have expanded our expertise for understanding the human health-relevant relationships between the risks of contaminants and the healthful benefits of long chain omega-3 fatty acid consumption. Samples of red drum collected from a variety of wild and farmed, domestic and imported sources have been analyzed for fatty acids and contaminants. Significant differences in fatty acid profiles were found, probably related to dietary differences. Most contaminant levels were insignificant, although high levels of DDT were found in farmed fish from two sources. A 62-sample survey of shrimp was completed and awaits completion of fatty acid and contaminant analyses. A DHA-enriched finishing diet study was conducted with red drum. Although the results are inconclusive, they have led to improved experimental designs for future diet studies. A large study raising red drum on diets in which fish meal/fish oil is greatly reduced or totally absent is currently underway. While lipid analyses have not yet been conducted, we are gaining valuable insight into improved operation of the HML Aquatic Production facilities. Shrimp and feeds from a highly successful, organic certifiable diet study were analyzed for fatty acids and chemical contaminants. Results will be published soon in a refereed journal. In the search for approaches to develop more healthful and nutritious cultured seafoods, studies have been expanded to investigate naturally occurring microbial communities as supplemental, contaminant-free nutrition sources.

Unresolved Issues:

- Because of uncertainty about future budgets, our plan is to complete all projects (red drum survey results dissemination, shrimp survey analyses, red drum diet study) currently underway, but not to start new endeavors until funding concerns can be clarified.
- The ability to expand our efforts to examine seafood risks and benefits in interesting ways such as working directly with epidemiologists at USC's School of Public Health, expanding surveys to additional species and markets, or running a variety of diet trials is limited by budgetary constraints. This severely limits the time, personnel, and equipment required to decrease turn-around time and to expand the number of samples that can be analyzed internally or to provide the means to purchase analyses externally.

Budget Report:

Salary expenditures and associated fringe and indirect have proceeded according to budget projections. Contractual expenditures and funding for materials and supplies have been disbursed for fish and shrimp samples, shipping costs, lab supplies and diet manufacturing supplies. Some expenditures have also been made for transportation associated with diet studies and sampling carried out at the Waddell Mariculture Center.

OHH Seafood Quality and Risks
Through October 2006

	Expenditures			
	Year 1	**Year 2**	**Year 3**	**Total**
Salaries	35,508.89	44,421.44	3,114.50	83,044.83
Hourlies	0.00	382.36	0.00	382.36
Fringe	11,305.01	15,654.40	1,140.19	28,099.60
Contractual	1,236.04	918.58	0.00	2,154.62
Fixed	0.00	68.50	0.00	68.50
Supplies	5,328.34	18,186.89	665.59	24,180.82
Transportation	394.98	603.48	0.00	998.46
Indirect	4,078.58	7,608.25	0.00	11,686.83
Total	57,851.84	87,843.90	4,920.28	150,616.02
Revenue	177,330.00	500.00	45,084.00	222,914.00
Account Balance	119,478.16	32,134.26	72,297.98	72,297.98